Gasification of Juliflora Chips in a Circulating Fluidized Bed Gasifier

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Abstract

Gasification of Juliflora chips was carried out in a 0.156 m inner diameter and 5 m height circulating fluidized bed gasifier with sand of 250 μm diameter as the bed material and air as the fluidizing medium. The influence of equivalence ratio and gasification temperature on gas composition, gas yield, lower heating value and gasification efficiency was investigated. The gasification temperature and equivalence ratio were maintained in the range of 700 to 900ºC and 0.2 to 0.3 respectively. Equivalence ratio and temperature strongly influenced the gas composition. With an increase in equivalence ratio, the temperature and gas yield were increased decreasing the gas heating value. It was also observed that the increase of temperature also increases the gas heating value, gas yield and gasification efficiency. Comparison of present experimental data with findings of other studies of different biomass fuels is also discussed in this paper.

Keywords

Circulating Fluidized Bed; Gasification; Juliflora Chips; Equivalence Ratio; Gas Composition; Gas Yield

Introduction

The first part of the paper deals with a review of literature survey of the work done in the field of gasification. The second part demonstrates the experimental programme of the gasification process and finally, the results and conclusions are discussed in the third part. Circulating Fluidized Bed (CFB) technology has been successfully used in many fields, including power generation; cogeneration; biomass gasification; ore roasting and oil catalytic cracking. Numerous studies in this field have been reported in the earlier literature. Though CFB technology has been used in coal combustion and petroleum industry for more than two decades with great success, its practical application to biomass gasification is still quite limited [1]. There are several studies on gasification of different biomass fuels in a CFB gasifier in the last two decades [2-4].

Vander Drift et al. [5] successfully tested a total of ten different biomass fuels in a circulating fluidized bed gasifier called BIVKIN having 500-kWth capacity. Raskin et al. [6] presented the operating experience of Kymijarvi power plant located at Lahti in Southern Finland jointly owned by Laden and Lampovoima. The gasifier produced a product gas equivalent of 35-55 MW_{th} depending on the gasifier fuel moisture content reporting the gas heating value in the range of 1.6-2.4 MJ/Nm^3.

Kersten et al. [7, 8] introduced the novel multistage circulating fluidized bed gasifier. The riser consisted of several segments in series, each of which built up of two opposite cones. The results of the gasification tests were compared with the results of gasification tests in ECN's pilot CFB gasifier (100kg/h). Their experimental results exhibited that the hydrocarbon (CH_4, C_2H_4, etc) yield increased for higher gas residence times. Yin et al. [9] presented the demonstration project of 1MW CFB gasifier for rice husk and reported the gas heating value in the range of 4.7 to 6.2 MJ/Nm^3.

Chen et al. [10] investigated the experimental results of miscanthus pellets in a 83 cm diameter and 6 m-height CFB gasifier with a thermal capacity of 100 kW. Their experimental results support their concept as a promising alternative to gasify biomass for the generation of electricity. Petersen and Werther [11] conducted experiments on sewage sludge gasification in a 0.1m diameter and 15 m height circulating fluidized bed pilot plant. In their study the air ratio was chosen as 0.3 and 0.6 and the temperature was maintained in the range of 750ºC to 850ºC. The influence of the air ratio, superficial gas velocity, temperature, and feeding height on the product gas composition was examined.

Lee et al. [12] studied the pyrolysis behaviour of wood pellet using 67.9mm diameter and 5.1 m tall circulating fluidized bed as a first step to develop the gasification system. The produced gas composition in the CFB gasification system was 53% CO, 16% CH_4 and 19% H_2 in riser temperature of 1073K. Sheeba et al. [13] investigated the gasification results of coir pith using CFB gasifier. The influence of temperature and equivalence ratio on the gas composition was reported.

A literature survey demonstrates that different types of models have been developed for gasification systems like kinetic, equilibrium and others [14-16].

The government of India launched a national programme on biomass gasification in 1986. Since then over 1600 gasifiers, equivalent to 22 MW capacity, have been installed all over the country, and about 150 gasifier systems are being installed every year [17, 18]. Research and development projects for the development of 100% biomass-based producer gas engine have been taken up [19]. Though the downdraft and fixed bed type gasifiers are commercially used in India, fluidized-bed type gasifiers are in an advanced stage of commercialization. Fluidized bed gasifiers have been the focus of appreciable research and development and there have been several commercialization projects over the last ten years. It has been proved that the CFB gasifier can operate over a broad range of operating conditions with satisfactory gasification results. Based on these, CFB gasification of biomass seems to be a quite promising way. Nowadays, gasification process is looking forward to the renaissance after successful commissioning of the biomass Atmospheric Circulating Fluidized Bed (ACFB) gasifier at the Kymijarvi Power Station in Lahti, Finland [2]. Table 1 shows the present work along with data from earlier studies.

A brief review of literature reveals that the information on biomass gasification in a CFB gasifier is very limited. It appears that no work has been carried out for gasification of Juliflora wood chips in a CFB gasifier in India. The aim of the present work is to study the gasification characteristics of Juliflora chips in a CFB gasifier. The influences of various operating parameters are analyzed.

TABLE 1 LITERATURE DATA WITH PRESENT WORK

Ref.	Size of CFB gasifier (m)	Ht. (m)	Type of Biomass	Equivalence ratio	Bed temp. (ºC)	% of CO	% of CO_2	% of H_2	% of CH_4	Gas heating value (MJ/Nm^3)	Gas yield (Nm^3/kg)	Gas. Effi. (%)
Present work	0.156 dia.	5	Juliflora chips	0.2 – 0.3	700 – 900	21- 26	7 - 20	7 - 10	1.7 – 3.5	4.3 – 5.6	1.6-1.95	52-73
Li et al. [3]	0.10	6.5	saw dust	0.2-0.60	700-850	6.9-21.4	15-18.3	3.0-7.3	1.4-4.6	2.43-6.13	1.72-3.30	44.2-64.7
Wu et al. [4]	2.0	8.5	Rice husk	0.12-0.30	700-800	16-21	15-16	5-8	4-6	5.45-6.4	-	-
Van der drift et al. [5]	0.20	6.0	Ten residual biomass fuels	0.32-0.60	803-861	5.34-11.65	13.94-17.10	1.80-9.02	1.24-3.30	2.05-5.13	-	56-66
Kersten et al. [7, 8]	-	6	Willow and pine wood	0.0-0.4	740	33	19	1.9	8	-	-	65-70
Yin et al. [9]	1.8 (1MW e cap.)	8	Rice husk	0.2-0.25	700-850	15-19	14.5-16.2	0.4-7.7	4-8.8	4.7-6.2	2.2	65
Chen et al. [10, 14]	0.83	6	Mis canthus	0.2-0.5	753	12.57	16.02	6.0	2.45	3.46	1.79-1.85	-
Sheeba et al. [13]	0.050	1.3	Coir pith	0.18-0.31	650-1028	30-48	38-55	6-12	6.0-7.7	3.0-5.7	1.01-1.15	55-60
Xiao et al [20]	0.212 square	1.25	Animal waste	0.3-1.0	600-700	7-15	20-25	39-47	4-8	8-10	1.0-1.2	-
Garcia-Ibanez et al. [22]	0.20	6.5	Olive oil waster	0.41-0.73	753-893	6.9-8.6	19-21.7	5.4-9.3	1.8-3.0	2.9-3.8	2.9-5.6	-
Zhou et al. [23]	-	-	Sawdust Rice husk	0.175-0.24 0.22-0.26	600-900	-	-	-	-	6.0-6.5 5.0	-	77 81
Meng et al. [24]	0.83	5.5	Agrol, Willow DDGS	0.33-0.47	730-820	22-27 20-24	35-41 37-45	22-25 23-28	37-43 34-40	2.7-3.9 3.7-4.2	2.48 2.63	-

Experimental Set Up

Fig. 1 shows the schematic view of Circulating Fluidized Bed (CFB) gasifier experimental facility used in the present study. It consists of 0.156 m inner diameter and 5 m height with refractory insulated over the surface of the gasifier to prevent the heat loss. The CFB gasifier consists of a riser, smooth C-Shaped exit, cyclone separators, return leg, Fuel feeder and an electrical heater. Cyclone separators, standpipe and an L-Valve are used for recirculation of the solids back into the CFB riser. In addition, the gasifier exit, cyclone separators, recycling line and L-valve are protected with outside insulation in order to minimise heat losses. The CFB gasifier is equipped with instruments like thermocouples, flow meters, pressure transducers with a data acquisition system. Thermocouples (T) were equipped with the CFB riser at different positions of 4.5, 44, 48.5, 85, 349, 370.5, 449 and 464.5 cm from the distributor plate. To monitor the temperature of bottom and upper zone of the CFB gasifier, the temperature probes were used. The temperature probes were connected to a centralized data acquisition and control system. Data acquisition system was used to indicate the temperature in a digital scanner

The particulates in the producer gas like ash, char, tars and alkali metals were cleaned and removed by means of a gas cleaning system which contains (i) Cyclone separators (ii) Ceramic filter and (iii) water scrubber. The hot producer gas with particulates was passed through a first cyclone, where the coarser particles in the producer gas were captured and it was recycled back to the bottom of the riser through the L-Valve. The gas leaving the first cyclone was passed through a second cyclone where ash got separated and got collected in an ash drum. The hot producer gas leaving the second cyclone was again cleaned using a ceramic filter unit. For internal combustion engine applications the producer gas was cooled to ambient temperature in a wet scrubber.

The gas sampling ports were located after the scrubber. Gas samples were collected using gas sampling bags for different operating conditions and the concentrations of producer gas were analyzed using a gas chromatograph. Juliflora wood chips used for experimental studies were of smaller size and powdery in nature. These chips contained 81.8 % of volatiles and small proportion of other elements. The lower calorific value of wood residues used for experimental studies was found to be 15.5 MJ/kg.

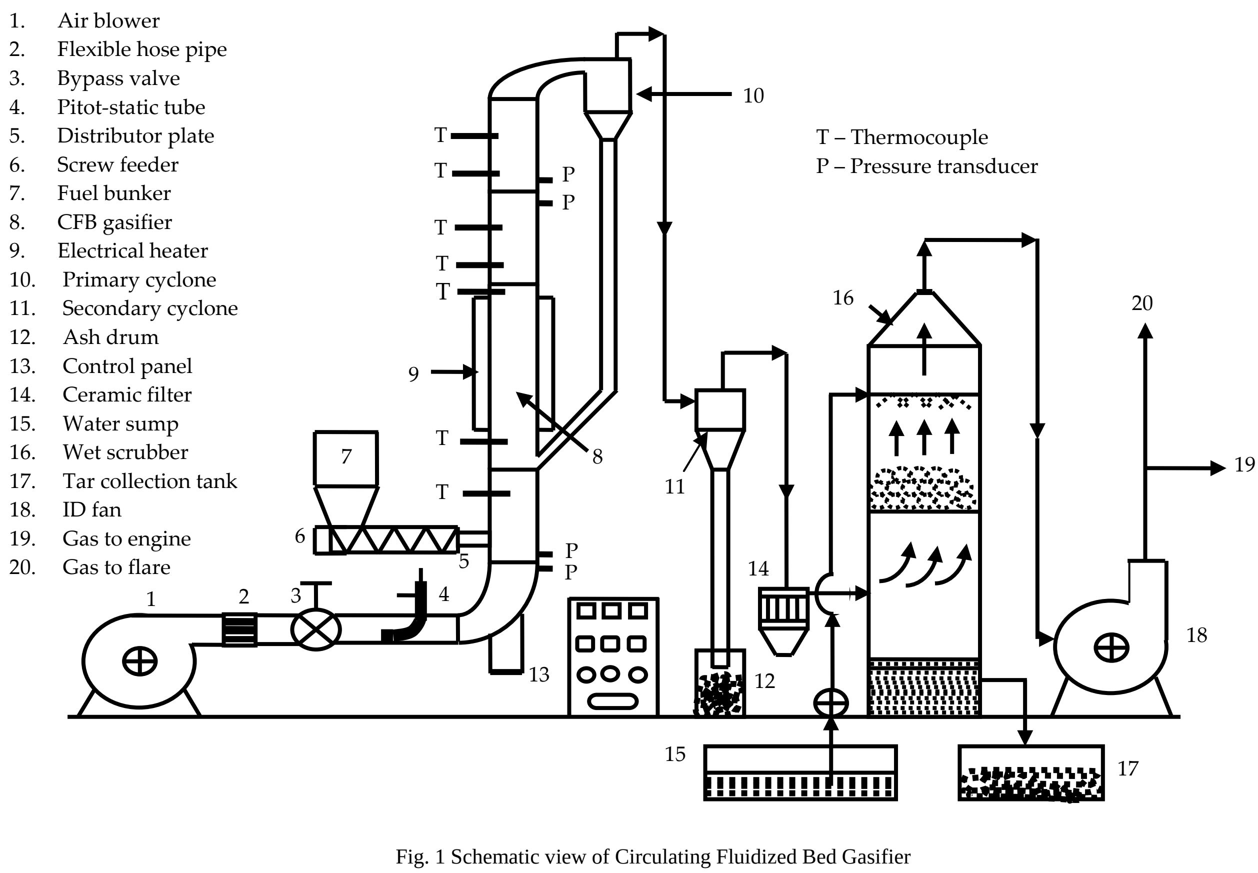

Fig. 1 Schematic view of Circulating Fluidized Bed Gasifier

TABLE 2 ULTIMATE AND PROXIMATE ANALY SIS OF JULIFLORA WOOD CHIPS (DRY BASIS)

Ultimate analysis (wt %)		**Proximate analysis (wt %)**	
Carbon	45.55	Moisture	12.10
Hydrogen	6.44	Volatile matter	81.80
Oxygen	47.22	Fixed carbon	16.34
Nitrogen	0.583	Ash	1.86
Sulphur	0.205		

TABLE III EXPERIMENTAL CONDITIONS

Feed stock	**Juliflora wood chips**
Fuel feed rate	5 – 65 kg/h
Bed material	Silica sand of mean diameter 250 μm
Gasification medium	Air
Fluidization velocity	0.14 – 4 m/s
Gasification temp.	700 – 900ºC
Equivalence ratio	0.2 – 0.3

The Primary air required for gasification was supplied through a multiorifice type distributor plate at the bottom of the riser from an air blower. Biomass was fed into the CFB gasifier using a screw type feeder. An electrical heater installed at the riser wall was utilized to preheat the gasifier to 400–550ºC to maintain a desired bed temperature level before biomass fuel was fed. After preheating, it was then switched to the gasification mode. The atmospheric air supplied for gasification was measured and controlled by flowmeters and regulating valves. The temperature at various points in the gasifier was measured for each experiment in a central control system. All equipments were stopped after collecting all the data. In order to cool the gasifier and to stop further reactions, air blower was operated continuously to supply air until the bed temperature dropped to a desired level.

Results and Discussion

Effect of Equivalence Ratio on Gas Composition

The influence of equivalence ratio on gas composition, temperature, heating value and gas yield is presented in Fig.2 to Fig.5. Comparison of present work with published results of others studies concerned with different fuels under almost similar conditions is also presented. As seen from the Fig. 2 it can be clearly seen that the equivalence ratio significantly affects the gas composition. It is observed that increase in equivalence ratio increases the concentration of CO_2 from 7 to 20% and decreases CO, H_2 and CH_4 as expected. The increase in CO_2 is mainly due to the cracking of heavier hydrocarbons, improved tar cracking and other reactions leading to higher temperature (reported in the earlier studies). An experimental result of Juliflora chips in a CFB gasifier is not available for comparison in the available literature. Similar trend is observed by Sheeba et al. [13] in the experimental results of coir pith under identical condition. The higher value reported by them is mainly due to the physical properties of the coir pith used by them. For comparison, all the experimental data are read out from the graph reported in the earlier studies (prone to uncertainty to a considerable extent). Considering the differences in design and operating conditions of the present experiments, this trend is quite satisfactory.

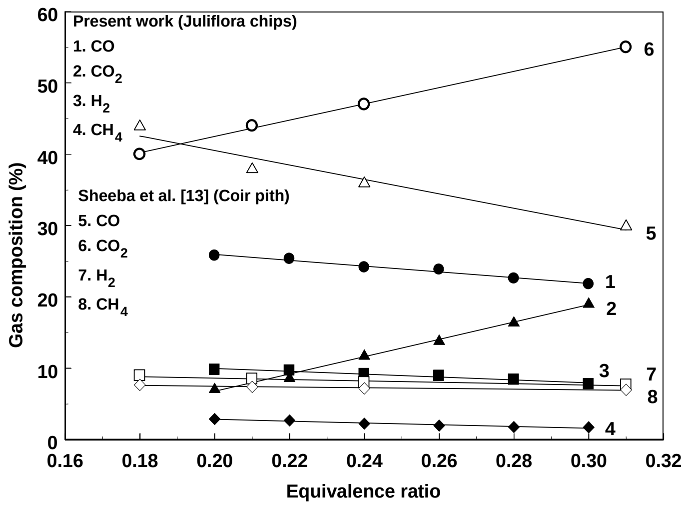

Fig. 2 Effect of equivalence ratio on gas composition

Effect of Equivalence Ratio on Bed Temperature

Fig. 3 shows the variation of bed temperature with equivalence ratio. It can be observed that the increase in equivalence ratio linearly increases the bed temperature. One can explain that at higher equivalence ratio more amount of air is introduced into the gasifier resulting in exothermic reaction of thermal decomposition leading to complete combustion process. Comparison of present data with other works on different fuels exhibits the similar variation.

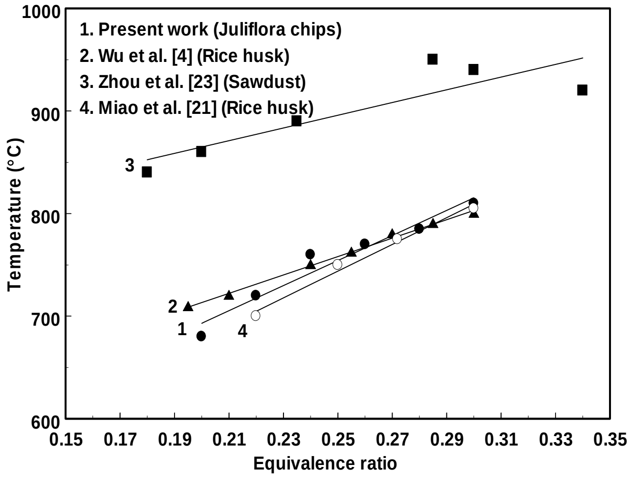

Fig. 3 Effect of equivalence ratio on temperature

Effect of Equivalence Ratio on Gas Heating Value

The influence of equivalence ratio on gas heating value is shown in Fig.4. It is found that the gas heating value decreases from 5.6 to 4.3 MJ/Nm^3 with increase in equivalence ratio. This is mainly due to dilution of nitrogen present in the air used as gasification medium and subsequent increase of CO_2. Experimental results of other works are also presented for comparison. In all the cases it is observed that the gas heating value is strongly affected by the equivalence ratio. The result of the one dimensional model developed by Sanz and Corella [16] using pine wood chips is also presented for comparison which shows that they are within acceptable deviation.

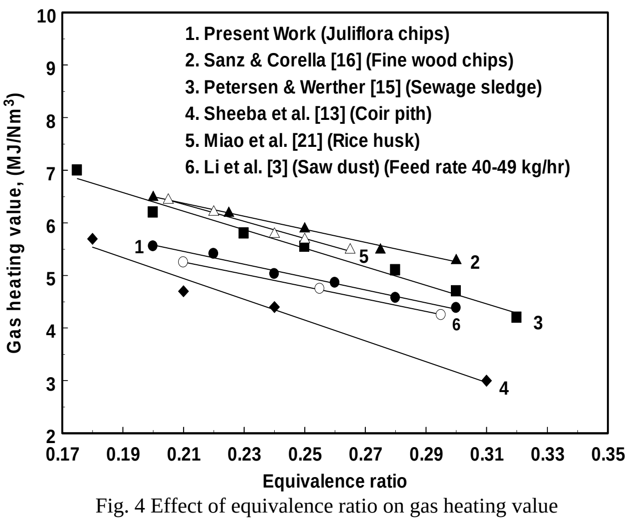

Fig. 4 Effect of equivalence ratio on gas heating value

Effect of Equivalence Ratio on Gas Yield

The increase in gas yield with equivalence ratio is shown in Fig.5. It is observed that gas yield is significantly increased from 1.6 to 1.95 Nm^3/kg due to the increase in both air and fuel feeding rate being converted into gaseous fuel with higher equivalence ratio. This result supports experimental findings of Sheeba et al. [13] who reported the gas yield of 1.1 to 1.624 Nm^3/kg using coir pith as a biomass fuel.

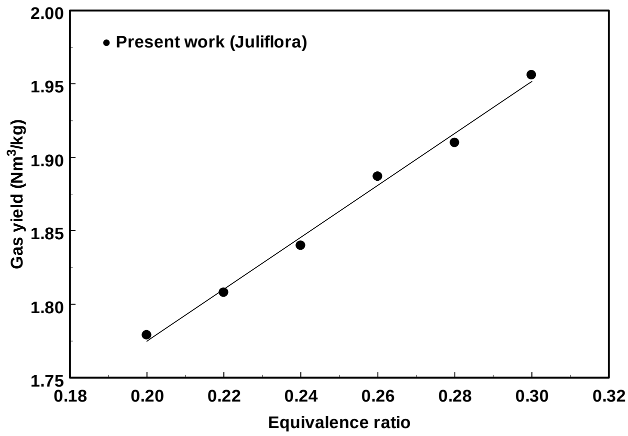

Fig. 5 Effect of equivalence ratio on gas yield

Effect of Temperature on Gas Heating Value

The influence of temperature on gas heating value in present work and other works is shown in Fig.6. It is interesting to note that the gas heating value increases with increasing bed temperature as depicted in the present work also shown by Li et al. [3] whereas according to other studies, it decreases. Wu et al. [4] reported that supplied heat is derived from the combustion enthalpy of biomass resulting in higher temperature mainly due to more fuel for combustion and less for gasification process producing lower heating value. Similarly Yin et al. [9] reported the lower value due to moisture content of rice husk, feeding rate and discharge of ash.

Effect of Temperature on Gas Yield

Fig. 7 shows the strong influence of temperature on gas yield. As the temperature increased, the gas heating value increased mainly due to conversion of solid fuel into gaseous fuel resulting in higher gas yield. Also shown is the similar trend observed by Sheeba et al. [29].

Effect of Temperature on Gasification Efficiency

The prediction of gasification efficiency with temperature is shown in Fig.8. It is observed that gasification efficiency increased in the range of 52 to 73 % with bed temperature.

Effect of Temperature on Gas Composition

The predicted result of gas composition on temperature is shown in Fig.9 to Fig.13. Comparison of different fuel used by others is also presented. As expected, it is clearly observed that the concentration of CO decreases with increase in temperature and increases the concentration of CO_2 as shown in Fig. 9 and Fig.10 respectively. Fig. 11 shows variation of H_2 as a function of temperature. It is worth mentioning that Xiao et al [20] reported H_2 in the range of 40 to 45 % and the rest of them within the range of 1 to 12 %. The higher value is probably due to thermal cracking and steam reforming as reported by them. The significant effect of temperature on CH_4 in present study as well as other works is shown in Fig. 12. It is clear that temperature plays a major role in case of gasification process. The variation of gas product with the temperature of the present work alone is shown in Fig.13. The combustible gases CO and CH_4 decrease due to increasing temperature. Opposite trend is observed in case of other gases.

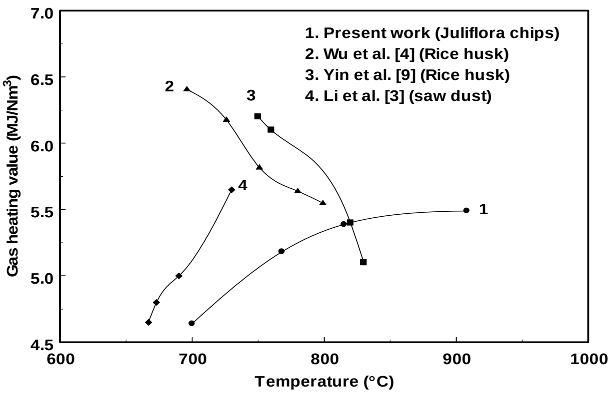

Fig. 6 Effect of temperature on gas heating value

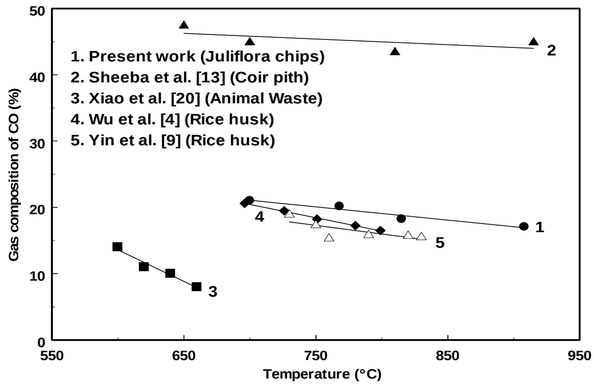

Fig. 9 Effect of temperature on gas composition of

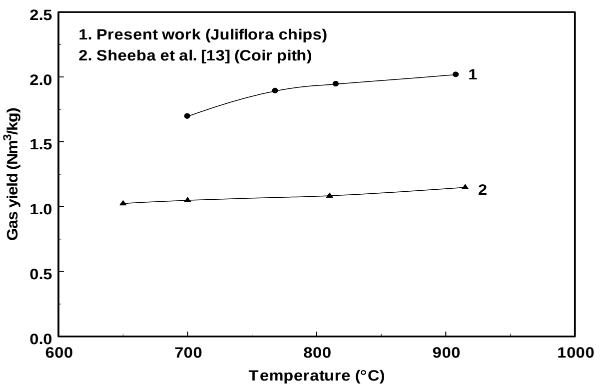

Fig. 7 Effect of temperature on gas yield

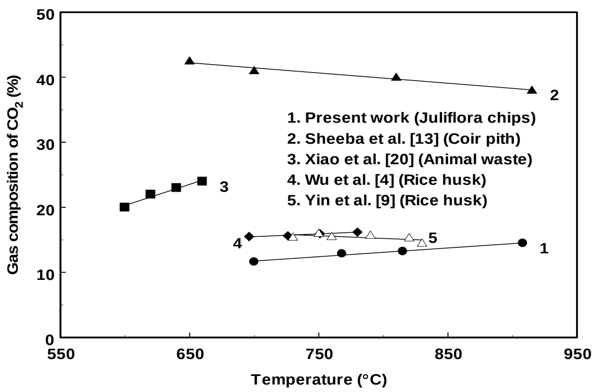

Fig. 10 Effect of temperature on gas composition of CO_2

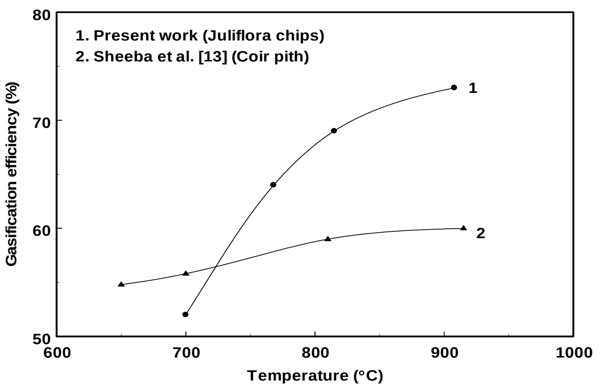

Fig. 8 Effect of temperature on gasification

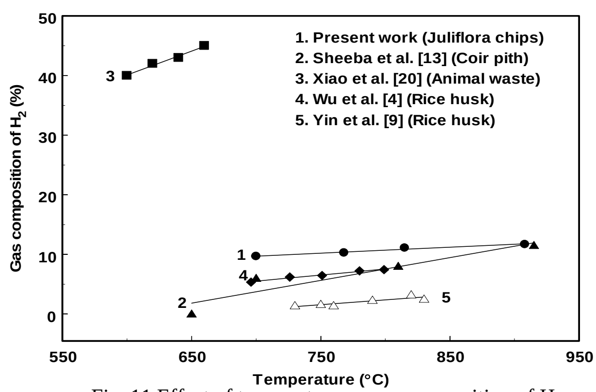

Fig. 11 Effect of temperature on gas composition of H_2

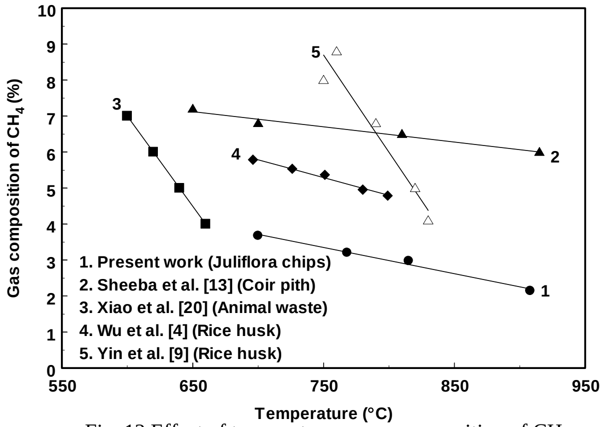

Fig. 12 Effect of temperature on gas composition of CH_4

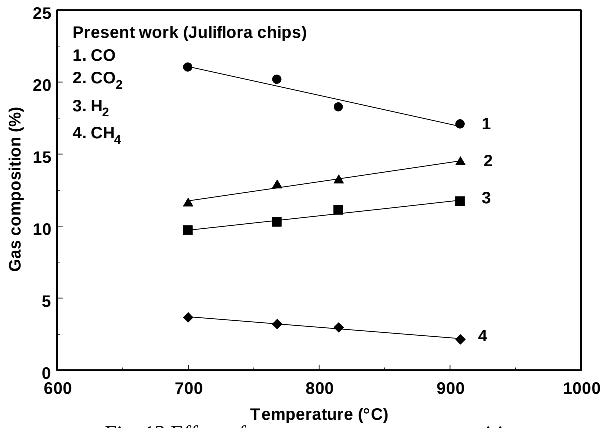

Fig. 13 Effect of temperature on gas composition

Conclusions

Following conclusions are drawn from the biomass gasification studies:

- Experiments were carried out to study the characteristics of Juliflora chips in a 0.15 m diameter and 6 m high CFB gasifier for the first time
- Influences of equivalence ratio and temperature on gas composition, gas heating value, gas yield and gasification efficiency were investigated
- With an increase in equivalence ratio from 0.2 to 0.3, the concentration of CO decreased from 26 to 21% and CO_2 increased to 7 to 22% and gas yield increased from 1.6 to 1.95 Nm^3/kg
- By increasing the bed temperature, the gas composition of CO_2 and H_2 increased linearly and CO and CH_4 decreased
- At higher temperature, the gas heating value of product gas was in the range of 4.3 to 5.6 MJ/Nm^3
- The present experimental data were compared with the published gasification results of different biomass fuels under almost similar conditions.
- Further research on theoretical model and its validation with experimental data are recommended

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